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SUBJECT: Path Loss for a Communications Link on the Lunar Surface - Case 320

DATE: June 1, 1970

FROM: N. W. Schroeder

ABSTRACT

Path loss calculations presented by K. Schmid for Apollo lunar surface VHF communications links have been extended. The following configurations are considered:

(1) Lunar Module - Extra Vehicular Astronaut (LM-EVA)

(2) Extra Vehicular Astronaut #1 - Extra Vehicular Astronaut #2 - (EVA-EVA)

(3) Extra Vehicular Astronaut - Lunar Communications Relay Unit (EVA-LCRU)

The following results were obtained:

1. Under equivalent soil conditions and for those surface distances that permit a line of sight path to exist on the lunar surface, a lunar surface transmission path has a path loss that is no more than 2 decibels greater than an equal length transmission path on the earth's surface. The greater curvature of the lunar surface is the cause of the higher losses in the lunar surface transmission path.

2. Increased surface roughness could provide significant additional margin in the performance of the radio link.

3. Variations in the pertinent soil parameters (conductivity (σ) and relative dielectric constant (ϵ_r)) will not affect the performance of the radio link significantly unless the magnitudes of these parameters lie far outside the ranges considered here for those parameters ($\sigma=10^{-5}$ to 10^{-3} mhos/meter, and $\epsilon_r=1.4$ to 4).

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MEMORANDUM FOR FILE

I. INTRODUCTION

The path loss, or attenuation, of a VHF radio signal transmitted over a spherical surface has been calculated for three possible Apollo communications configurations to provide an estimate of the expected performance of these lunar surface communications links on future Apollo missions.

The three communications links considered here are the following:

1. Lunar Module - Extra Vehicular Astronaut
   (LM - EVA)

2. Extra Vehicular Astronaut (1) -
   Extra Vehicular Astronaut (2)
   (EVA - EVA)

3. Extra Vehicular Astronaut - Lunar Communications Relay Unit
   (EVA - LCRU)

The path loss for these links was calculated for several sets of surface conditions that are believed to be representative of future Apollo missions. The effect, on this path loss, of the difference in the radius of curvature of the earth and moon, is also given.

Results of the path loss calculations are shown in Figures 1 through 4 as a function of surface distance between antennas. These plots are a composite of the results of three types of path loss analysis.

(a) For the region near the horizon and beyond, the calculations are based on the residue series analysis by H. Bremmer [2] presented in Reference 3.

(b) For the nearer line-of-sight region, the calculations are based on the geometric optics analysis used by K. Schmid, [1] and also J. F. Lindsey III [4]. The nearest and furthest bounds of the region where the optics analysis is valid, specular reflection region [1], are a function of the surface roughness [5] and the ratio of the wavelength to the radius of curvature of the transmission path [6] respectively.

(c) For the region near the transmitting antenna the path loss is simply equal to that of a free space transmission path.

For a reasonably smooth surface, the standard deviation of the surface irregularities are equal to or less than 0.25 meters, the transitions between the regions defined above are quite smooth. For example, in the case of the LM-EVA link the geometric optics and residue series calculations give essentially the same results for the range of surface distance from 600 to 1800 meters; the maximum difference is 0.5dB.

II. EARTH SURFACE VS LUNAR SURFACE TRANSMISSION PATH

Figures 1-3 present the path loss calculated, as discussed above, for the LM-EVA, EVA-EVA, and the EVA-LCRU configurations. These figures present the calculated path loss for a radio link on the surface of the moon and also the path loss for that link on the surface of the earth. The curves show that the lunar surface transmission path differs from the earth surface transmission path only for the region near the lunar horizon and beyond; this difference at a distance equal to the lunar horizon is only about 2 decibles. However, the validity of this comparison is dependent on locating the radio link on the earth where the surface parameters are those shown on the figures (ε_r=4, σ=10^{-3} mhos/meter), which corresponds to those parameters used by Lindsey in Reference [4].

III. LUNAR SURFACE ROUGHNESS

Figure 4 shows the effect of the variation in the surface roughness on the calculated path loss for the LM-EVA configuration. The roughness is defined as

$\Delta h \triangleq$ the standard deviation of the height of the surface irregularities

a Δh = 0.25 meters gives results that are within 0.5dB of the results obtained for a smooth surface. In the limit as the roughness increases, the path loss approaches that calculated for a free space transmission path. The Δh = 10 meters curve of figure 4 shows that for a roughness of 10 meters the path loss is still within 4dB of the loss calculated for a free space path at a distance of 1 km.

IV. LUNAR SOIL PARAMETERS

Path loss was calculated for the following magnitudes of soil parameters:

$$\sigma = 10^{-3} \text{ mhos/meter}, \ \varepsilon_r = 4$$

$$\sigma = 10^{-5} \text{ '' '' }, \ \varepsilon_r = 1.4$$

For a further discussion of estimates for these parameters obtained from measurements see References [7, 8, 9]. The differences between the path loss calculated using the four possible combinations of the above parameters, are only 0.2dB.

V. CONCLUSIONS

1. The path loss of a radio link on the lunar surface exceeds, but by no more than 2 decibels, the path loss of an equal length radio link located on the earth's surface - provided that the surface distance between the antennas is no greater than the distance to the lunar horizon. The lunar horizon distance is defined as the maximum surface distance between two antennas on the lunar surface that permits a line of sight path between them. The added attenuation of the lunar surface transmission path results from the greater curvature of the lunar surface.

2. The surface roughness can be a significant factor in the performance of a lunar surface radio link. The performance of a system designed on the basis of a perfectly smooth surface should always provide comfortable margins in the event that increasingly rougher surface conditions are encountered, provided that a line of sight path remains.

3. If the lunar soil parameters lie in the assumed

ranges of

$$\sigma = 10^{-3} \text{ to } 10^{-5} \text{ mhos/meter}$$

$$\varepsilon_r = 1.4 \text{ to } 4.0$$

a variation in soil parameters does not cause a significant variation in path loss.

N. W. Schroeder

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N. W. Schroeder

Attachments
Figures 1 thru 4

REFERENCES

1. Schmid, K. H., Propagation Characteristics of the Apollo Dual-EVA Communications Links, TM 68-2034-13, Bellcomm, Inc. August 12, 1968

2. Bremmer, H., Terrestrial Radio Waves, Elsevier Publishing Co., 1949.

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4. Lindsey, III, J. F., Lunar Surface Transmission Loss For The Apollo Astronaut, NASA TND-4915, National Aeronautics & Space Administration, December, 1968.

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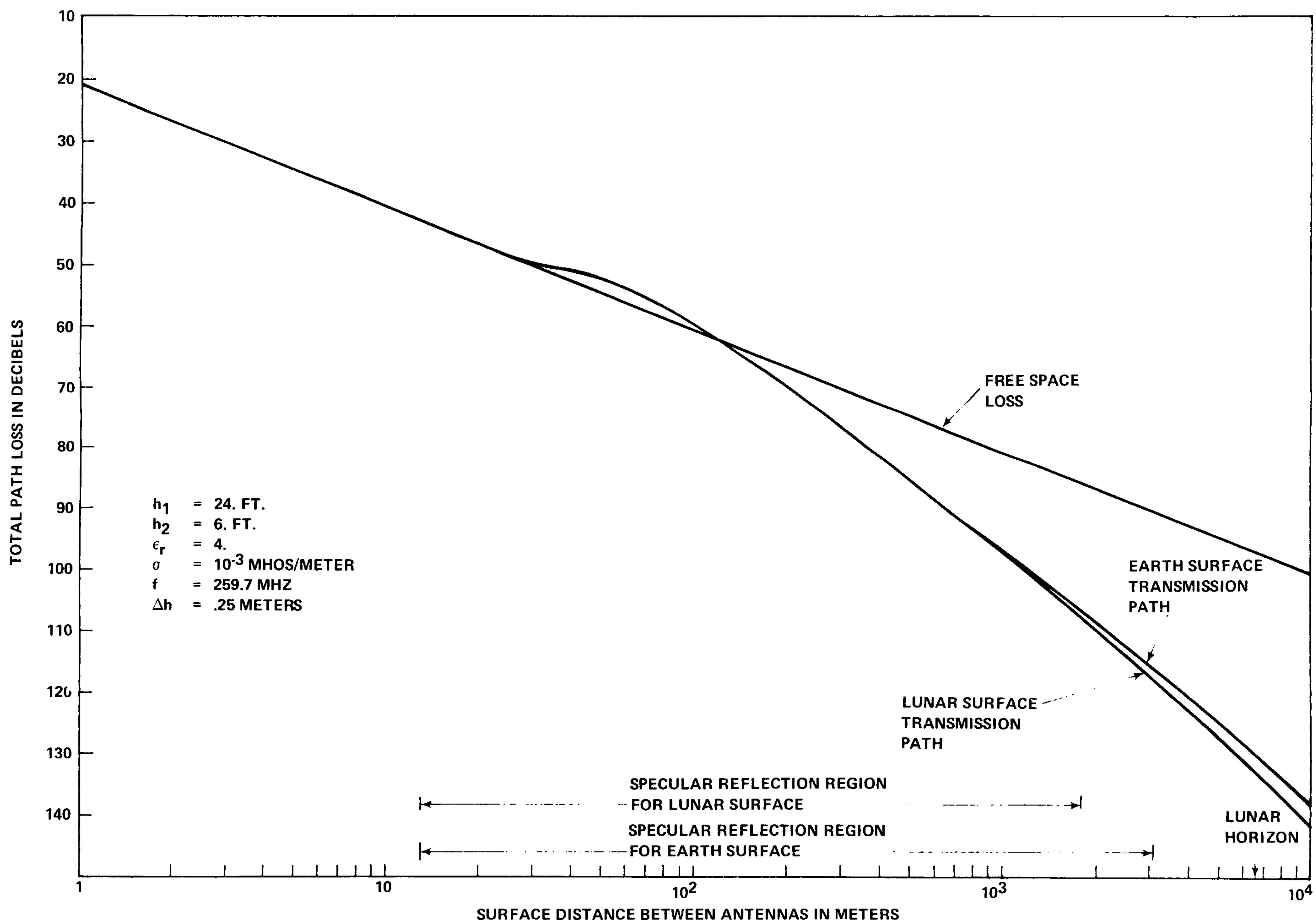

FIGURE 1. COMPARISON OF LUNAR SURFACE AND EARTH SURFACE TRANSMISSION PATHS LM-EVA CASE

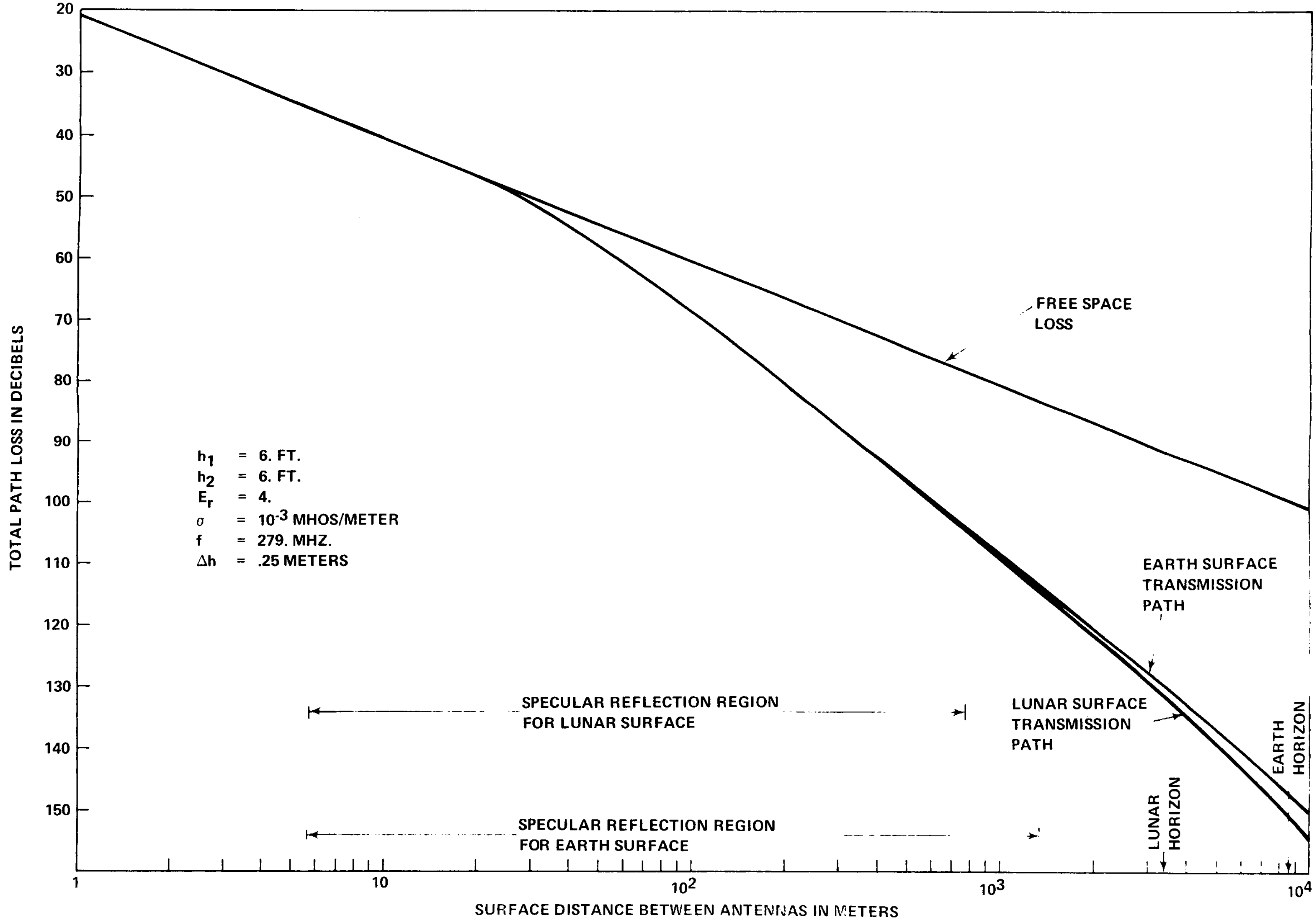

FIGURE 2. COMPARISON OF LUNAR SURFACE AND EARTH SURFACE TRANSMISSION PATHS
EVA-EVA CASE

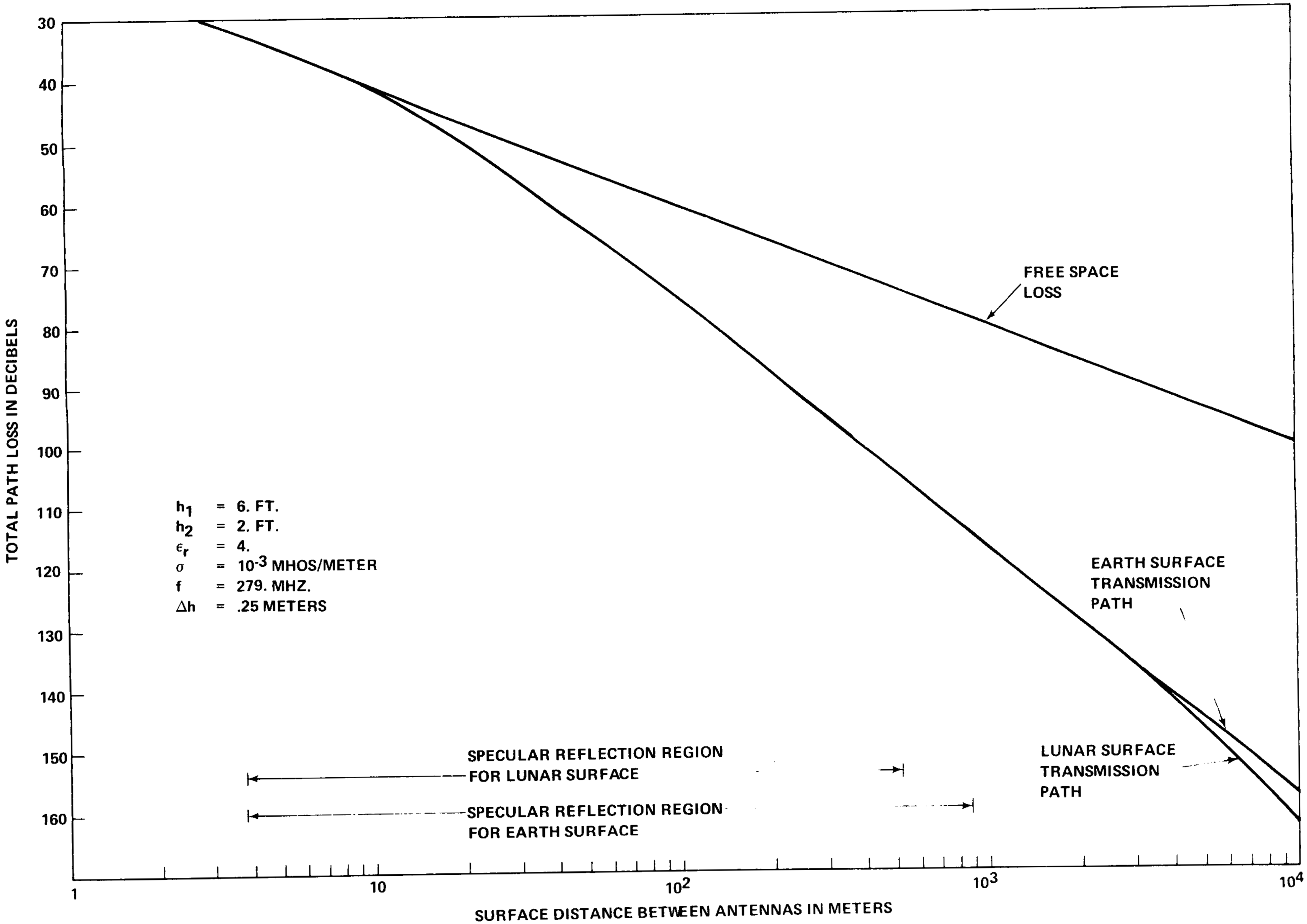

FIGURE 3. COMPARISON OF LUNAR SURFACE AND EARTH SURFACE TRANSMISSION PATHS
EVA-LCRU CASE

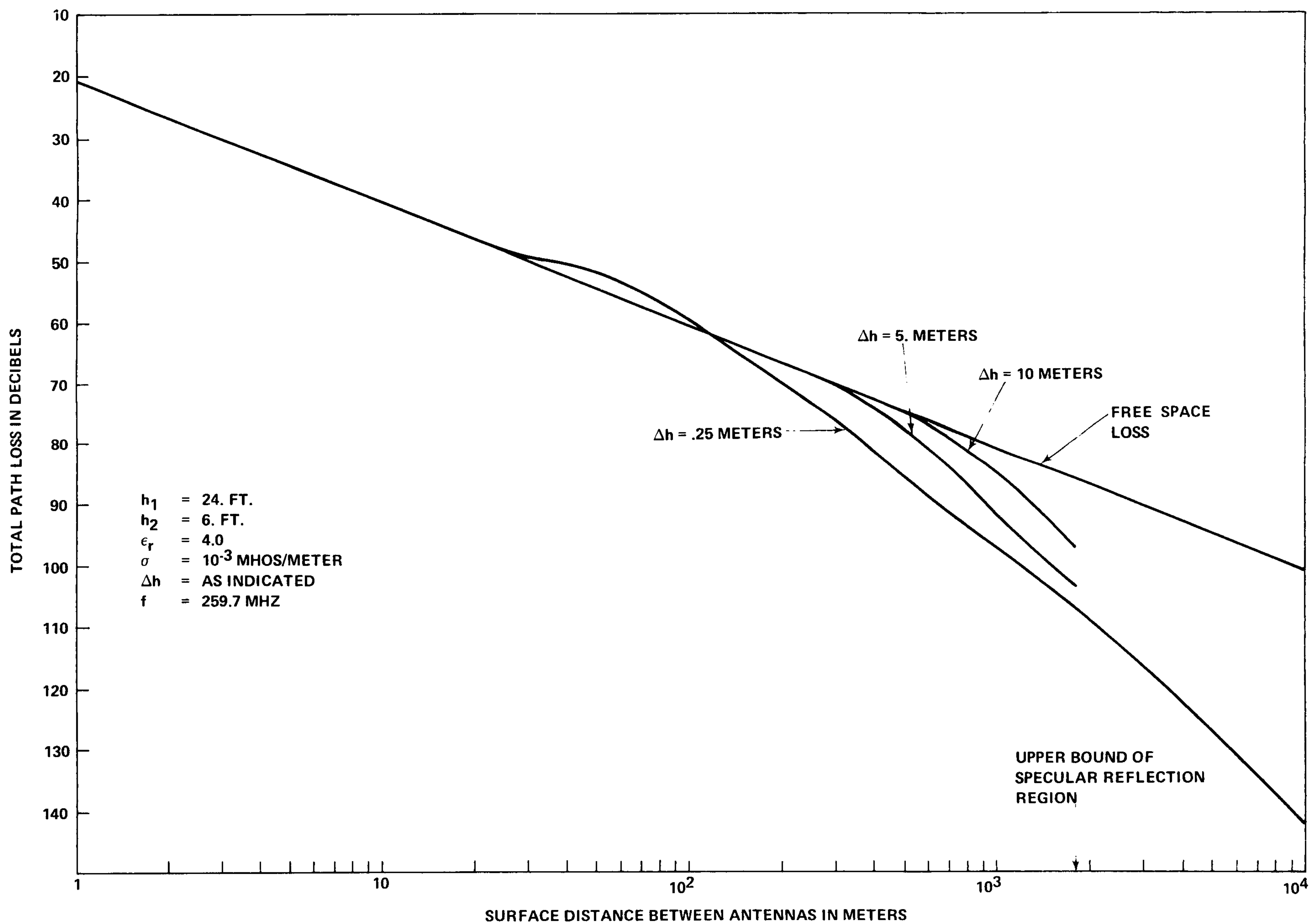

FIGURE 4. REDUCTION IN PATH LOSS RESULTING FROM INCREASED LUNAR SURFACE ROUGHNESS LM-EVA CASE

APPENDIX

Path Loss Equations

Purpose:

The purpose of this appendix is to present the equations that were used in calculating the path loss for the radio links discussed in the text of this memorandum.

Figures 1 to 3 in the text are plots of path loss as a function of surface distance between antennas of a radio link operating over a rough spherical surface. Three distinct regions are labeled on these figures; the basis for defining these regions lies in the character of the radio signal that exists at the receiving antenna. Near the horizon and beyond, surface wave region, the received signal is comprised essentially of the surface wave that can be calculated using the residue series analysis by Bremmer [2]. At nearer distances where a line of sight path exists between the antennas, specular reflection region, the received signal is comprised of the vector sum of the signals traveling directly between the two antennas and those signals which are reflected from the spherical surface. Near the transmitting antenna and up to a distance defined by the Rayleigh criteria, diffuse reflection region, the rough spherical surface reflects the incident signal diffusely; therefore, the received signal is essentially the same as that for a transmission path in free space.

I. Diffuse Reflection Region (Region near transmitting antenna)

Since the signal reflected from the surface in this region causes only neglegible interference with the signal that travels between the antennas via a direct path, the path loss for this region is essentially equal to that of a free space path.

$$\text{Path loss}_{(I)} = 20 \log_{10} R_{FS} + 20 \log_{10} F_{MHz} + 32.45 \text{ (dB)} \quad (1)$$

R_{FS} = Direct path distance between antennas in kilometers

F_{MHz} = Carrier frequency in megahertz

II. Specular Reflection Region (Region extending beyond diffuse reflection region to near horizon)

In this region the received signal is calculated using the geometric optics analysis. (2)

$$\text{Path loss (II)} = 20\log_{10} R_{FS} + 20\log_{10} F_{MHz} + 32.45$$

$$-10\log_{10}\left[\left(\frac{|\Gamma|}{1+\frac{\delta_{path}}{R_{FS}}}\right)^2 + \frac{2|\Gamma|\cos\Theta_{RF}}{1+\frac{\delta_{path}}{R_{FS}}} + 1\right] \text{ (dB)}$$

Γ = Reflection coefficient of rough spherical surface.

$= \Gamma_{rms} \; |\Gamma_o| \; \text{Div}$

$$\Gamma_{rms} = \left\{ \exp\left[- \left(\frac{4\pi\Delta h \sin\gamma}{\lambda}\right)^2\right]\right\}^{1/2}$$

Δh = Standard deviation of the height irregularities of the spherical surface in meters.

γ = Grazing angle of the reflected signal.

λ = Wavelength of the carrier signal in meters.

Γ_o = Plane surface reflection coefficient.

$$= \frac{\bar{\varepsilon}_c \sin\gamma - (\bar{\varepsilon}_c - \cos^2\gamma)^{\frac{1}{2}}}{\bar{\varepsilon}_c \sin\gamma + (\bar{\varepsilon}_c - \cos^2\gamma)^{\frac{1}{2}}} = |\Gamma_o| \underline{/\Theta_\Gamma}$$

$\bar{\varepsilon}_c = \varepsilon_r - j60\sigma\lambda$

ε_r = Relative dielectric constant of the surface material.

σ = Conductivity of the surface material in mhos/meter.

Div = Divergence resulting from the geometrical configuration of the radio link.

$$= \left\{ 1 + \frac{2R_{R1}\, R_{R2}}{R_A\left(R_{R1} + R_{R2}\right)\sin\gamma} \left(1 + \sin\gamma + \frac{2R_{R1}\, R_{R2}}{R_A\left(R_{R1} + R_{R2}\right)} \right) \right\}^{-\frac{1}{2}}$$

R_A = Radius of curvature of the spherical surface in meters. See Figure A-1 for definition of remaining terms.

δ_{path} = Difference in path length between direct and reflected paths in meters.

$$\Theta_{RF} = \Theta_{\Gamma} + 2\Pi \frac{\delta_{path}}{\lambda}$$

The bounds of the specular reflection region are defined in terms of the grazing angle (γ).

$$\text{nearest bound} \quad \gamma_{max} = \sin^{-1}\left[\frac{\lambda}{8\Delta h}\right] \tag{3}$$

$$\text{furthest bound} \quad \gamma_{min} = \tan^{-1}\left[\frac{\lambda}{2\Pi R_A}\right]^{\frac{1}{3}} \tag{4}$$

III. Surface Wave Region (Region near and below horizon)

In this region the received signal is calculated using the residue series derived by Bremmer.

$$\text{Path loss (III)} = 20 \log_{10} R_{SD} + 20 \log_{10} F_{MHz} + 32.5 \tag{5}$$

$$- 20 \log_{10} (2A_1\, F_s)$$

$$F_s = \text{shadow factor} = (2\pi)^{\frac{1}{2}}\ \xi^{\frac{3}{2}} \left| \sum_n \frac{e^{-j\tau_n \xi}}{1 + \frac{2\tau_n}{\delta}} \right| F(h_1)\ F(h_2)$$

A_1 = Plane earth gain factor

$$= \left\{ \frac{2\Pi}{\lambda} \; \frac{|\bar{\varepsilon}_c - 1|}{|\bar{\varepsilon}_c|^2} \; R_{SD} \right\}^{-1}$$

R_{SD} = Surface distance between antennas

ξ = Distance factor

$$= \left(\frac{2\Pi}{\lambda R_A^2} \right)^{\frac{1}{3}} R_{SD}$$

δ = Ground parameter

$$= \left(\frac{2\Pi R_A}{\lambda} \right)^{\frac{2}{3}} \left(\frac{\bar{\varepsilon}_c - 1}{\bar{\varepsilon}_c^2} \right)$$

$*F(h_{1,2})$ = Antenna height gains

$$= 1 + j \left[\frac{2\Pi h_{1,2}}{\lambda} \; \left(\frac{\varepsilon_c - 1}{\varepsilon_c} \right)^{\frac{1}{2}} \right]$$

*Expression is valid for $h_{1,2}$ = Heights of antennas in meters $h < 30\ \lambda^{\frac{2}{3}}$ only.

τ_n = Mode numbers

τ_1 = $1.856 \angle -\Pi/3$

τ_2 = $3.245 \angle -\Pi/3$

$$\tau_3 = 4.382 \underline{/-\Pi/3}$$

$$\tau_{n\geq 4} = \frac{1}{2}\left[3\Pi\left(n+\frac{3}{4}\right)\right]^{\frac{2}{3}} \underline{/-\Pi/3}$$

IV. SKIN DEPTH OR ABSORPTION LENGTH

A wave starting at the surface of a conductor is attenuated as it propagates inward. The magnitude of this attenuation is a function of the properties of the conductor and the wavelength of the wave propagated. Since the wave inside the conductor is normally attenuated very severely, the field is localized in a thin surface layer whose thickness is referred to as the skin depth or absorption length of the conductor. By defining the thickness of this layer equal to the distance that the wave can be propagated, inside the conductor before the wave is attenuated to 1/e (36.8%) of its initial magnitude at the surface, the measurable skin depth and the properties of the conductor can be related as follows*:

$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}} = \text{skin depth or absorption length in meters} \quad (6)$$

ω = $2\Pi f$ radians/second

μ = $4\Pi x 10^{-7}$ henry/meter

σ = conductivity of conductor in mhos/meter

solving for the conductivity gives

$$\sigma = \frac{f_{mhz}}{(36\Pi^2 x^2)(10^3)} \quad \text{mhos/meter}$$

f_{mhz} = Frequency of wave in MHz

x = Absorption length measured in wavelengths.

* Time Harmonic Electromagnetic Fields, Roger F. Harrington, McGraw-Hill Book Company, 1961.

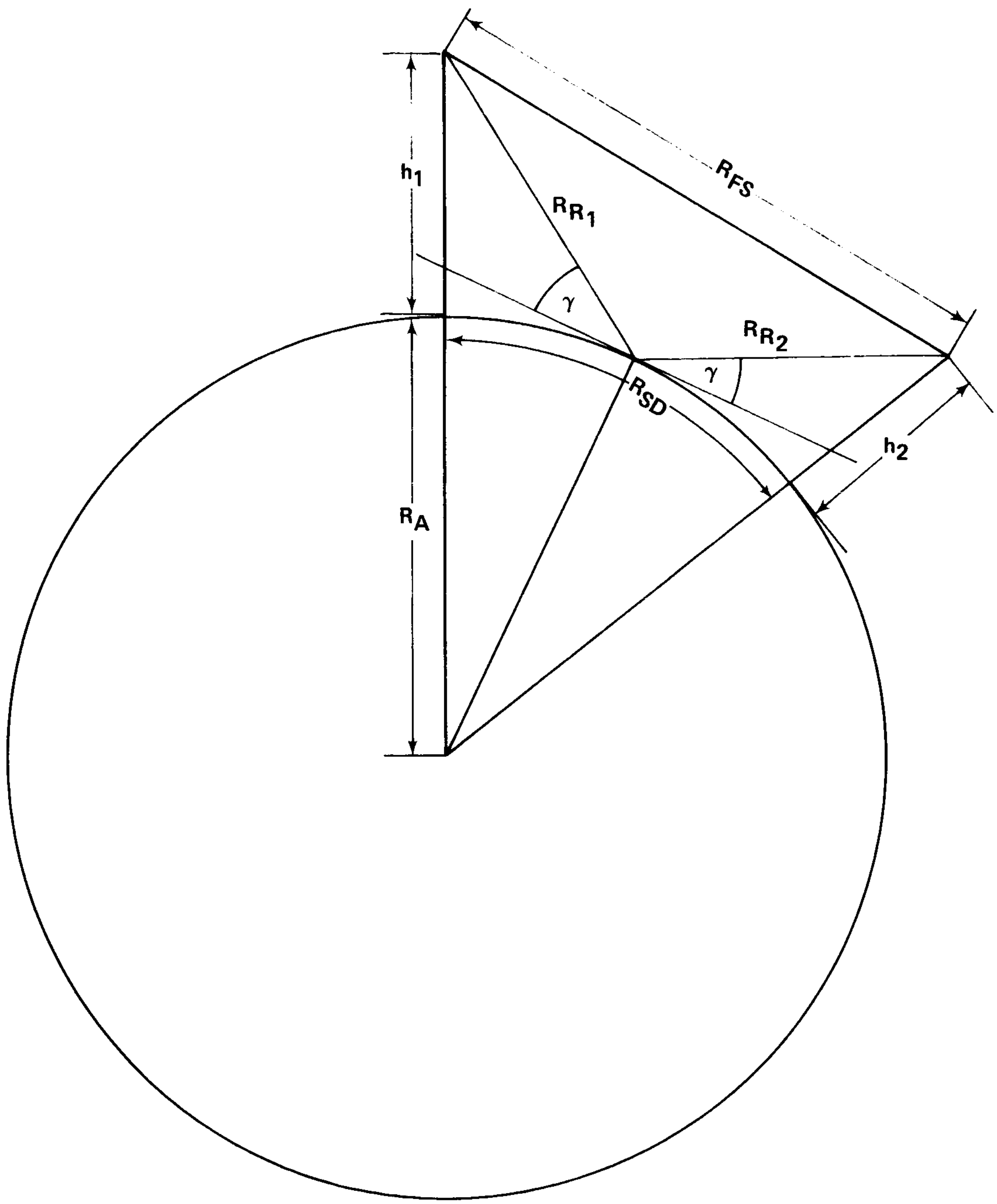

FIGURE A-1. GEOMETRY FOR REFLECTION REGION

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